# PROPOSED DAMAGE-RISK CRITERION FOR IMPULSE NOISE (GUNFIRE) (U)



W. Dixon Ward, Editor



NAS-NRC Committee on Hearing, Bioacoustics, and Biomechanics

Working Group 57

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W. Dixon Ward

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NATIONAL ACADEMY OF SCIENCES - NATIONAL RESEARCH COUNCIL
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# PROPOSED DAMAGE-RISK CRITERION FOR IMPULSE NOISE (GUNFIRE) (U)

Report of Working Group 57

W. Dixon Ward, Chairman and Editor

Sg. Cdr. R.R.A. Coles
Lt. Col. John Fletcher
Georges Garinther
J. Donald Harris
David Hodge
Michel Loeb
James D. Miller
Horace O. Parrack

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## I. Introduction

In 1964, the Committee on Hearing, Bioacoustics and Biomechanics of the National Research Council (CHABA) proposed a set of damage-risk criteria (DRC) for intermittent and continuous steady-state noise (Kryter, Ward, Miller and Eldredge, 1966). These criteria were based on the assumption that the permanent hearing losses (noise-induced permanent threshold shift, or NIPTS) eventually produced by many years of exposure to noise is approximately equal to the auditory fatigue (temporary threshold shift, or TTS) shown by a normal ear after a single day's exposure. A corollary of this assumption is that exposures which produce equal TTSs will produce equal NIPTSs. Therefore, in order to derive DRC for a wide range of exposures, it was merely necessary to select a value of TTS that should not be exceeded, and then determine from a study of the literature what noise exposures (expressed in terms of level, duration, and rate of interruption) produced precisely this TTS. The CHABA curves cited above were based on the assumption that the acceptable values of $TTS_2$ (TTS measured two minutes after cessation of exposure to the noise) were 10 dB at 1000 Hz and below, 15 dB at 2000 Hz, or 20 dB at 3000 Hz or above.

Unfortunately, at that time little information on TTS produced by impulse noise existed, and even this was somewhat ambiguous. It was therefore not judged possible to estimate what pattern of impulse-noise exposure would produce, in the average person, the TTSs cited above. The only specific statement in the CHABA proposal regarding impulse noise was therefore the following: "While exact limits cannot be set, the Working Group did find evidence that repeated exposure to some types of acoustic impulses exceeding 140 dB in the earcanal of the listener can result in significant losses of hearing in some persons."

In the intervening period, several studies at laboratories both here and in England have dealt with a fairly large range of exposure to gunfire under controlled conditions. These recently were summarized by Coles, Garinther, Hodge and Rice (1968), who then proceeded to recommend a DRC for impulse noise based on these data, a DRC designed to protect seventy-five percent of the men exposed. The following proposal is patterned closely after the Coles et al criteria; however, the permitted values here are slightly different from theirs, for reasons cited in Section III.

## II. Proposed Criteria

### Definitions

Impulse noises are broken down by Coles et al into two general types, illustrated in figure 1, though intermediate forms do occur. Figure 1a shows the pressure waveform that is often observed when a gun is fired outdoors with no reflecting surfaces nearby, while figure 1b exemplifies a much more complicated situation: an initial series of damped oscillations which may be followed by a reflected wave at only a slightly lower level. The following terms must be defined, in order to specify the DRC for these two types of impulse noise.

(1) The peak pressure level (P) is the highest instantaneous pressure level reached at any time by the impulse, expressed in decibels re 0.0002 dyn/cm$^2$, measured at the position of the ear with the individual not present.

(2) The pressure-wave duration, or A-duration, is the time required for the initial or principal wave to reach the peak pressure level and return momentarily to zero. In figure 1a, this duration is from point V to point W.

(3) The pressure-envelope duration, or B-duration, is the total time that the envelope of the pressure fluctuations (positive and negative) is within 20 dB of the peak pressure level, including reflected waves. Thus in figure 1b, the B-duration would be from V to X, plus Y to Z. The specialized measurement techniques required for accurate determinations of P, A-duration and B-duration are discussed in detail by Coles et al.

### Basic Criterion

Figure 2 presents the fundamental criterion, a criterion intended to limit the $TTS_2$ produced in all but the most susceptible five percent of exposed individuals to the CHABA limits of TTS. This DRC represents the tolerance limits for 100 impulses distributed over a period of four minutes to several hours on any single day. It is assumed that the pulses reach the ear at normal incidence. In case of doubt as to which waveform analysis to apply, the more conservative B-duration should be used. The main features of the criterion are these:

(1) The maximum peak pressure level permitted is 164 dB (without ear protection) for the shortest pulses of any practical interest (25 microseconds).

(2) As duration increases, the permitted peak pressure level decreases steadily at a rate of 2 dB for each doubling of the duration, dropping to a terminal level of 138 dB for B-durations of 200 to 1000 milliseconds.

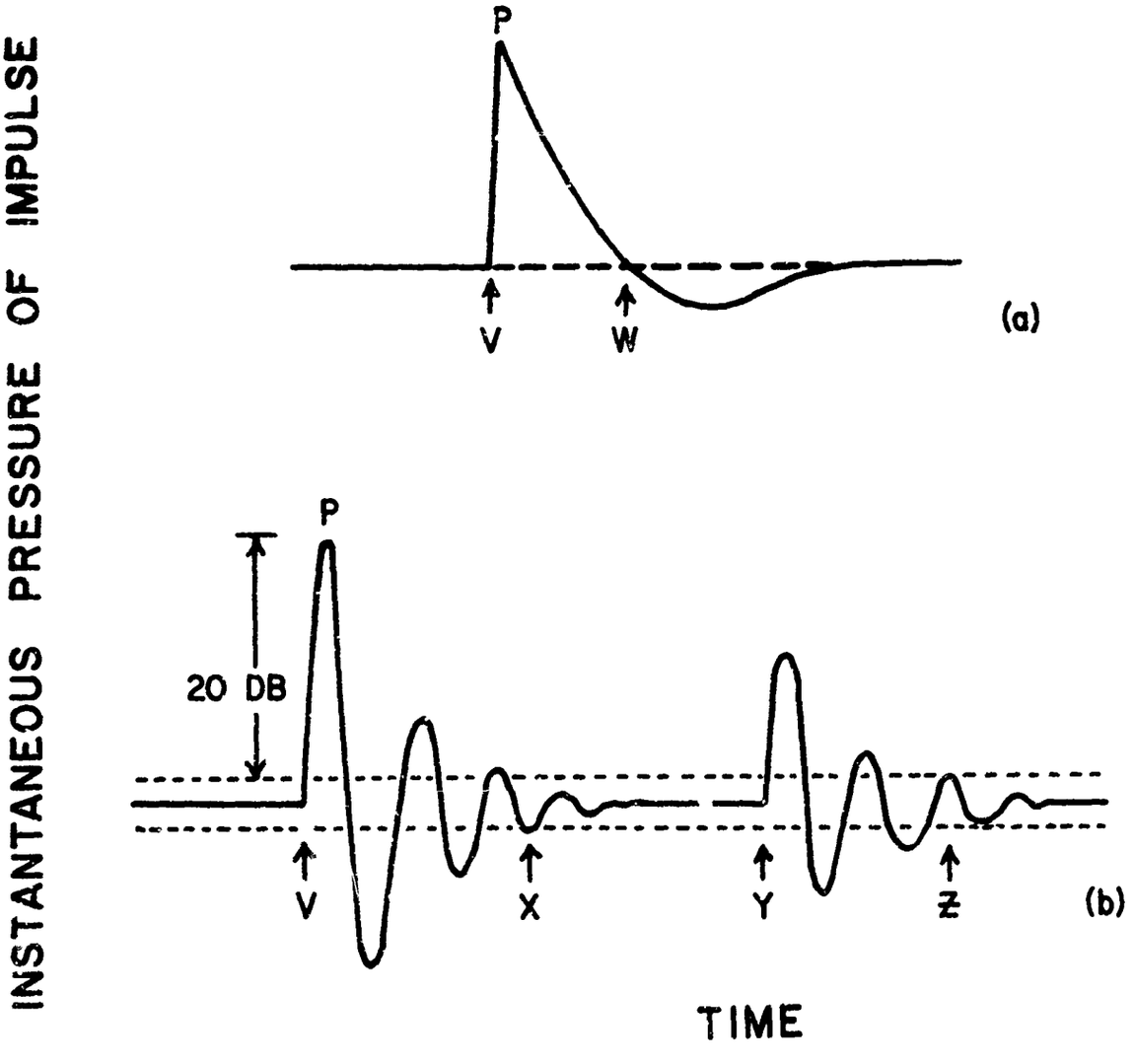


Fig. 1. Two principal types of impulse noise.

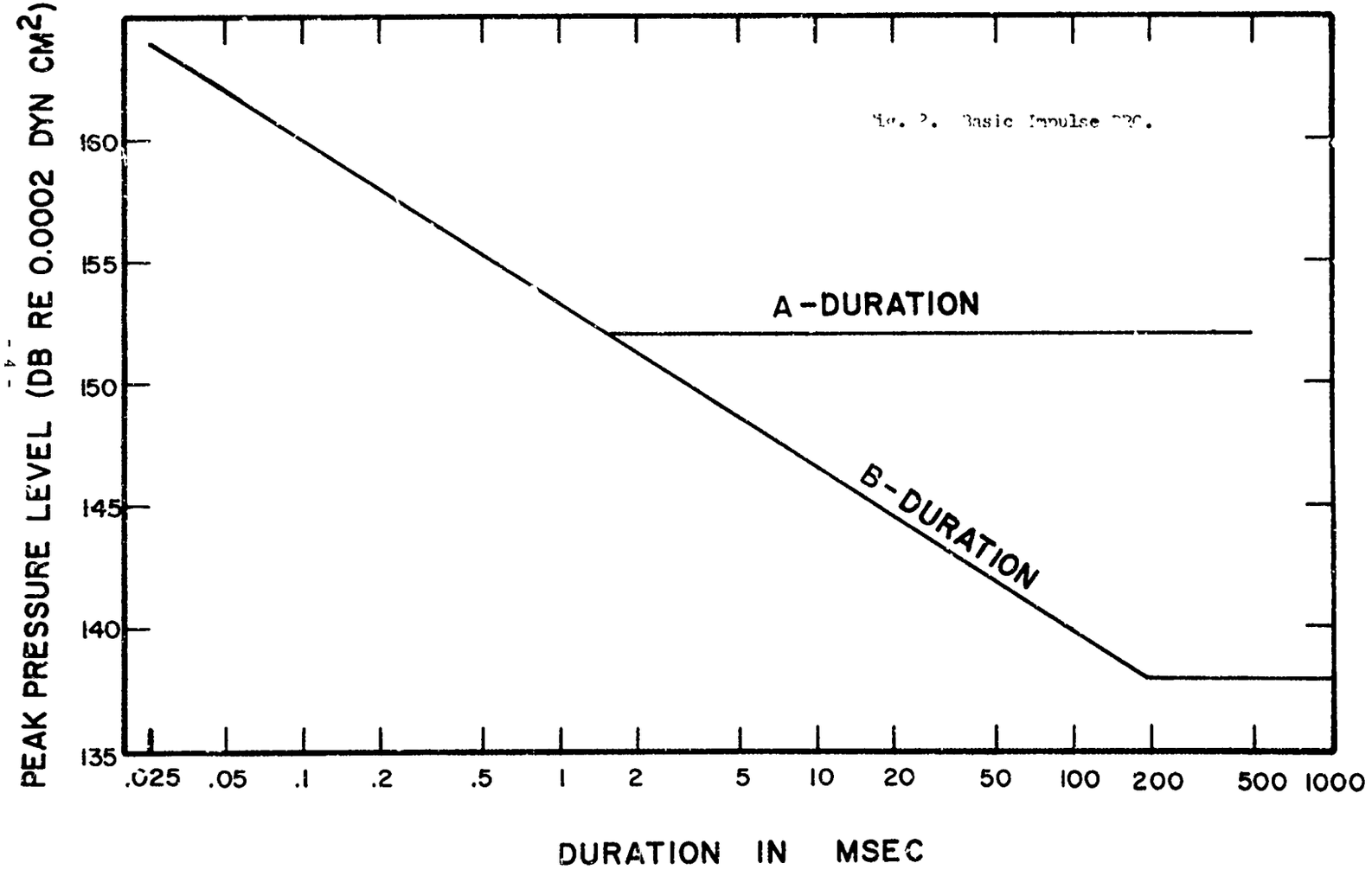


Fig. 2. Basic Impulse [illegible].

(3) A similar decrease occurs for A-durations, except that a terminal level of 152 dB is reached at about 1.5 milliseconds.

Correction Factors

In case the conditions stipulated for this basic criterion are not met, correction factors can be applied as follows:

(1) If the pulses arrive at the ear at grazing incidence instead of normally, the curves can be shifted upward 5 dB (that is, 5 dB can be added to the ordinate values in figure 2).

(2) If the number of pulses in an "exposure period" (that is, on any given day) is some value other than 100, an adjustment is made according to the curve in figure 3. This curve provides a 5 dB change in permitted level for each 10-fold change in number of impulses.

III. Explanation and Justification

The basic DRC of figure 2 is essentially 10 dB lower than the one proposed by Coles et al. Half of this difference (5 db) represents the difference between the two proposals as to whether direction of incidence of the impulses is assumed to be grazing or normal. Coles et al define their basic criterion in terms of grazing incidence, with a 5 dB decrease in allowable limits if the impulse arrives normally, while the present proposal does just the opposite, establishing limits for normal incidence, with a 5 dB increase in permitted level if arrival is grazing.

The other 5 dB by which the present criterion is more conservative than that of Coles et al stems from the fact that an attempt has been made here to protect ninety-five percent of the exposed personnel instead of seventy-five percent.

In the main, then, the basic criterion is not inconsistent with that of Coles et al. However, three changes are more substantive.

(1) At the high end, the termination of the basic DRC at 164 dB means that under no conditions should any ear be exposed to a peak level in excess of 179 dB which is the limit for a single pulse (+10 dB) at grazing incidence (+5 dB) with a 25 microsecond duration. Furthermore, the DRC is a straight line in contrast to Coles et al, whose criterion curves upward for very short pulses. These changes are consistent with some data gathered by Loeb and Fletcher (1968) after Coles et al had prepared their proposal. Loeb and Fletcher found that 30 dB of $TTS_2$ was produced in the median listener by one hundred 30 microsecond pulses whose peak level was 167 dB. Since Coles et al had at hand little data on TTS from pulses shorter than 200 microseconds on which to base their estimate, relying instead on some judgments of relative loudness of various pulses, the present criterion is considered more realistic.

(2) There is a "floor" of 138 dB for B-durations of 200 to 1000 milliseconds. This boundary reflects the fact that because of reflex contraction of the middle-ear muscles, the effect of acoustic energy entering the ear later than 100 to 200 milliseconds after onset of the pulse will be considerably reduced.

(3) A specific correction for number of pulses is established, as portrayed in figure 3. It will be noted that since a 10-fold change in number of impulses changes the DRC by only 5 dB instead of 10 dB, this correction factor is merely an interpolation and extension of a considered opinion expressed by Coles et al as follows: "Where exposure is to occasional single impulses only, it seems reasonable to raise the limits somewhat, and an estimate of 10 dB has been agreed upon for this."

## IV. Limitations

While these curves do no great violence to the published data on either TTS or PTS from impulse noise (as Coles, Garinther, Hodge and Rice show in some detail in the unabridged 1967 version of their recommendations) they admittedly represent only a first attempt at a reasonable DRC for impulses. Parameters that are ignored in the present criterion may eventually be shown to be important. For example, the rise time of the initial or principal pulse is not considered here, nor is the period of oscillation of an "B-duration" impulse. In addition, taking the effective B-duration to be the time needed to drop 20 dB from the principal peak pressure is rather arbitrary.

Futhermore, the 138-dB, and 152-dB plateaus are only gross estimates. The correction for number of impulses, too, is based on very limited data. Finally, this criterion, like the earlier CHABA DRC for continuous noise, rests heavily on the assumption of a consistent relation between TTS and PTS, and this may after all be incorrect.

It is expected, however, that this criterion designates reasonable limits for the type of impulse noise to which most service personnel will be exposed: rifle and pistol reports from his own and his fellows' weapons, and single rounds fired by higher-caliber armament in both reverberant and nonreverberant conditions. Even automatic weapon fire should probably be covered, if one considers each <u>burst</u> as a single "event". (The justification for this, once again, comes from the protective action of the middle-ear muscles, which provides some 10 to 20 dB of effective protection against all but the first round or two in the burst).

Thus if exposures are limited to the levels proposed here, either by control of the peak level or the number of pulses, or by use of adequate ear defenders, fewer than the most susceptible five percent of the exposed personnel will demonstrate temporary changes in auditory sensitivity so large that,if they were to become permanent, they would constitute beginning auditory handicap.

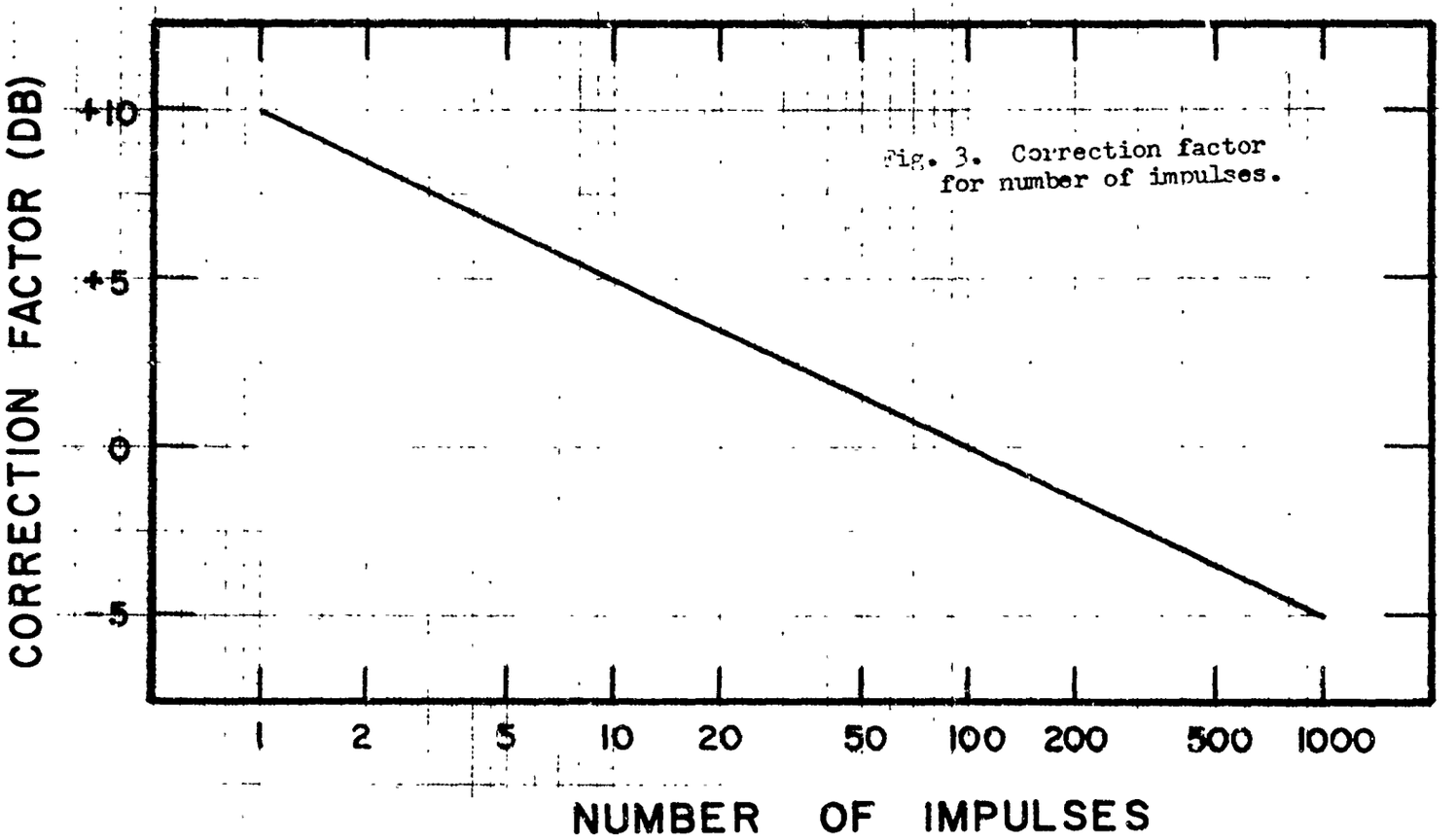


Fig. 3. Correction factor for number of impulses.

It is intended that the limits for impulse-noise exposure outlined in this document should apply as often as operational and/or safety conditions permit. For instance, ear protectors should always be worn on firing ranges and on most occasions of field firing exercises and other forms of weapon training, practice, or proving. It is not intended to imply that ear protection should be worn when actually in combat, except where weapons are fired from positions out of the immediate zone of fighting. Even in the immediate zone of fighting ear protection may sometimes be advantageous. The effective loss of hearing produced by use of an ear protector can be quickly eliminated by removal of the protector; on the other hand, the loss of hearing produced by the action of the noise on the unprotected ear requires many hours before recovery to normal hearing sensitivity occurs.

Not only is it necessary to protect personnel from eventual permanent threshold shifts, but for many operational situations it is imperative to protect against TTS, since sensitive hearing is often essential for patrol and sentry duty, or in tasks where auditory communication is critical. (In this respect, it is also necessary to protect the ears against TTS induced by non-impulse noise sources, such as helicopters and armered personnel carriers).

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